eRD6 Progress Report

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FOR *e*RD6

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

JANUARY 28, 2016

Stony Brook University | The State University of New York

Consortium Summary

- eRD6 Consortium consists of groups from
  - BNL
  - Florida Institute of Technology
  - Stony Brook University
  - University of Virginia
  - Yale University

Consortium Summary

- Groups are working on
  - BNL
    - Mini-Drift detector; TPC/Cherenkov prototype
  - Florida Institute of Technology
    - Large area GEM readout with zig-zag structures
  - Stony Brook University
    - Short radiator length RICH detector
  - University of Virginia
    - Large area GEM readout with u-v readout strips
  - Yale University
    - 3-D-coordinate GEM readout; hybrid gain structure

Published Results

- All groups published in peer-reviewed journals
  - BNL
    - "**A Prototype Combination TPC Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider**", C. Woody et al., Conference Proceedings of the 2015 Micropattern Gas Detector Conference, Trieste, Italy, October 12-15, 2015 (submitted).
    - "**A Study of a Mini-drift GEM Tracking Detector**", B. Azmoun et al., submitted August, 2015 to the IEEE Transactions on Nuclear Science, currently under review.
    - "**Study of a Short Drift GEM detector for future tracking applications at PHENIX**", M. Purschke et al., Conference Record Proceedings of the 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference, Seoul, Korea, October 2013.

Published Results

- All groups published in peer-reviewed journals
  - Florida Institute of Technology
    - A. Zhang et al., "**Performance of a Large-area GEM Detector Read Out with Wide Radial Zigzag Strips**," Nucl. Instr. Meth. A811 (2016) 30-41, doi: 10.1016/j.nima.2015.11.157
    - A. Zhang et al., "**R&D on GEM Detectors for Forward Tracking at a Future Electron-Ion Collider**," 2015 IEEE Nuclear Science Symposium Conference Record, Nov 1-7, San Diego, CA.

Published Results

- All groups published in peer-reviewed journals
  - Stony Brook University
    - "Performance of a Quintuple-GEM Based RICH Detector Prototype", M. Blatnik et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015.
    - "Performance of a Quintuple-GEM Based RICH Detector Prototype", Nuclear Science Symposium Conference Record, 2015, IEEE

Published Results

- All groups published in peer-reviewed journals
  - University of Virginia
    - K. Gnanvo et al. "**Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab**", Nucl. Inst. and Meth. A782, 77-86 (2015). DOI: 10.1016/j.nima.2015.02.017
    - K. Gnanvo et al., "**Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout**", Nucl. Inst. and Meth. A808 (2016), pp. 83-92. DOI: 10.1016/j.nima.2015.11.071.

Published Results

- All groups published in peer-reviewed journals
  - Yale University
    - A publication is in preparation on the 2-GEM+MMG results and presentations were made at Quark Matter 2015 and IEEE/NSS/MIC 2015.

Progress @ BNL

1. Progress from July 2015 - January 2016

- Completed the analysis of the test beam data from the Minidrift Detector. A paper on these results was submitted to the IEEE TNS in Aug 2015. It is currently being revised after its first review and the revised version will be resubmitted in early February 2016.

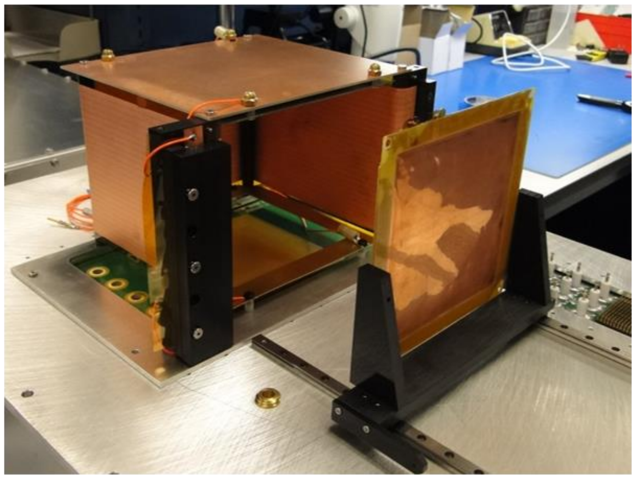
- Finished construction of the TPC/Cherenkov prototype detector except for installation of the CsI photocathode GEM, which we expect to do during the next few weeks. The TPC portion of the detector was tested with cosmic rays with a variety of different gases and performed very well.

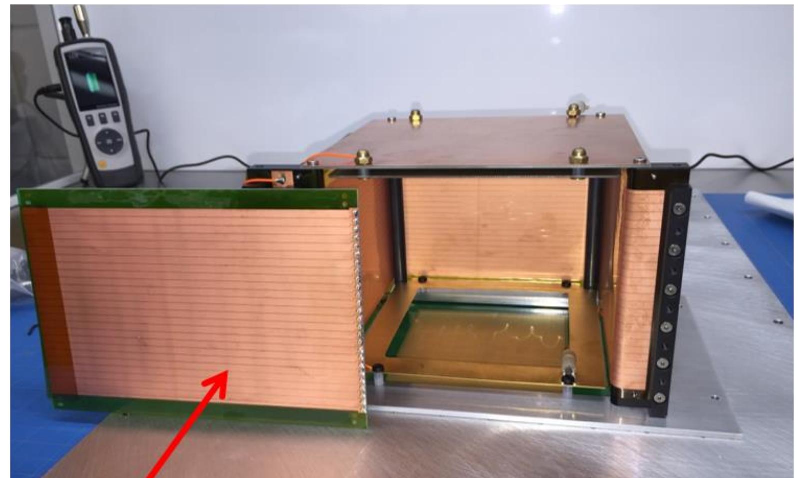
2. Expected progress from January 2016 – July 2016

- The photosensitive GEM will be installed and the Cherenkov portion of the detector will be tested in the lab. Pending the successful completion of these tests, the detector will be tested in the test beam at Fermilab in April 2016 to measure its performance as a combined TPC/Cherenkov detector.

Progress @ BNL

Field Cage for TPC only and TPC/Č operation





Wire field cage frame for TPC/Cherenkov operation

3 sided kapton foil field cage with removable fourth side kapton foil for TPC only operation

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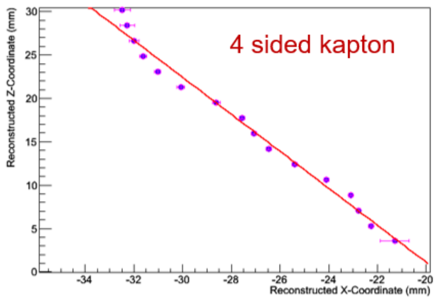
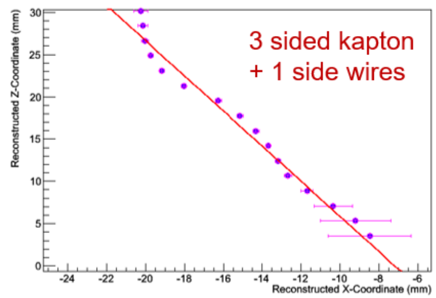
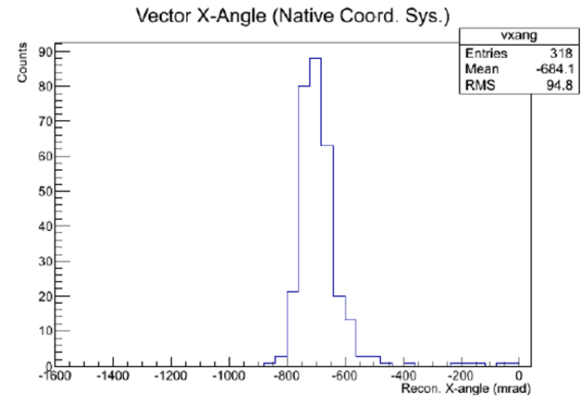
Progress @ BNL

Cosmic Ray Tracks in the TPC

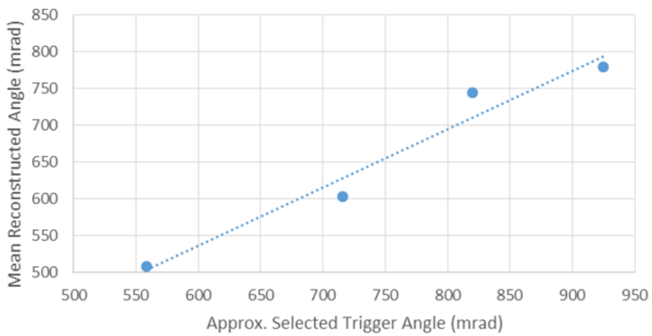




Cosmic ray tracks found in the TPC portion of the detector operating in Ar/CH_4 (80/20).



Distribution of angles of cosmic ray tracks measured in the TPC operating with *pure* CF_4 and the detector configured with the wire plane for TPC/Cherenkov operation.



Correlation between the angle of cosmic tracks measured in the TPC versus the angle of the track determined by the cosmic ray trigger counters.

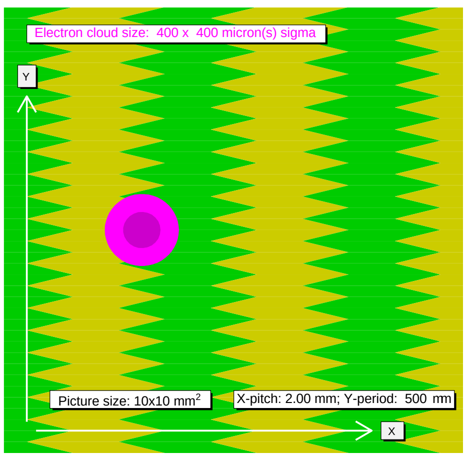
Progress @ Florida Tech

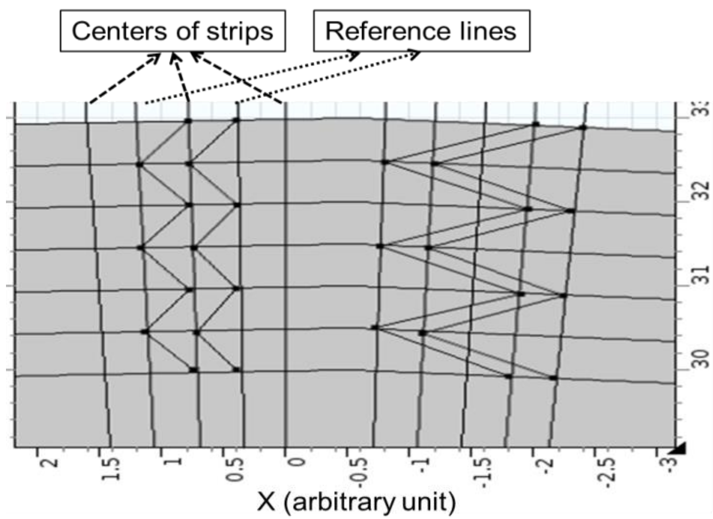
- Zig-zag readout design for the EIC forward tracking GEM prototype 2 shared by Florida Tech, UVa and Temple U.
- New mechanical stretching method and designs
- Detailed study of previous zig-zag readout
  - Scanning detector at BNL using 2D motor and collimated X-ray gun
- Small zig-zag board to be produced and tested → study improvement of spatial resolution

Progress @ Florida Tech

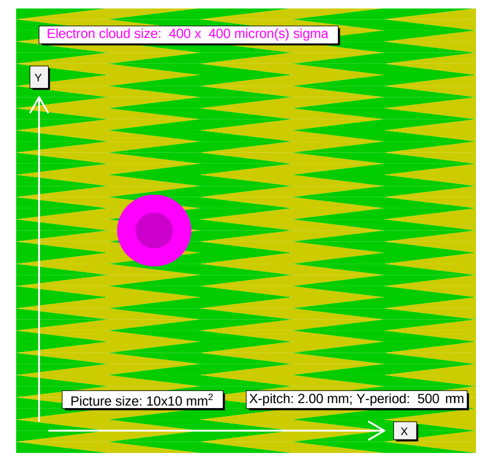
Two types of zig-zag structures and their non-linear responses to hit positions in a GEM detector reconstruction with charge centroid method.

Zig-zag structure previously used





New zig-zag design: **<u>tips on a strip interleave directly to centers of neighbor strips</u>**.



Progress @ Florida Tech

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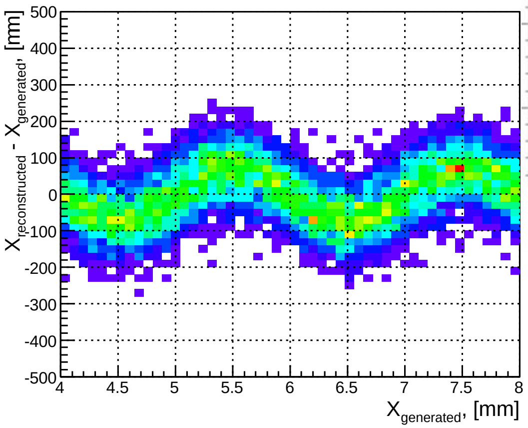

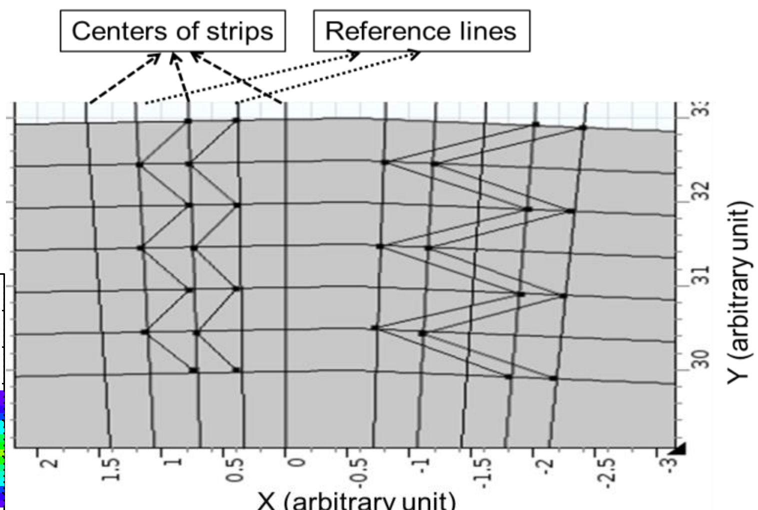

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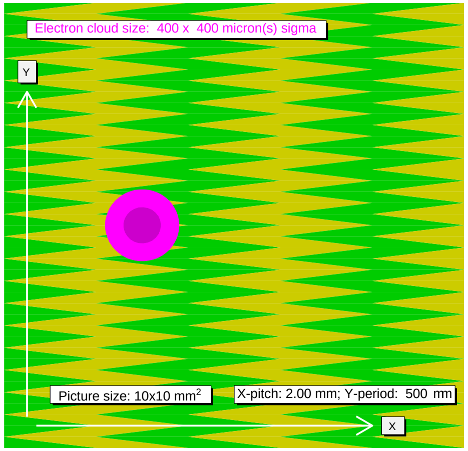

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Progress @ Florida Tech

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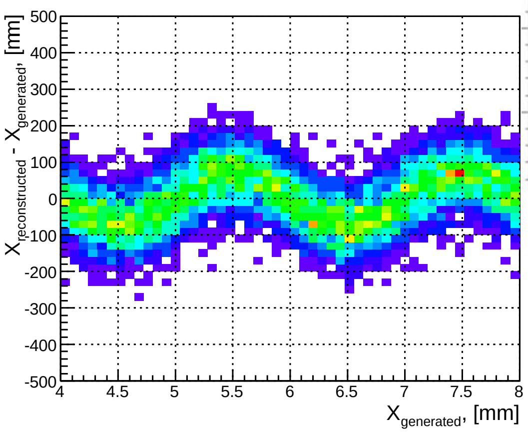
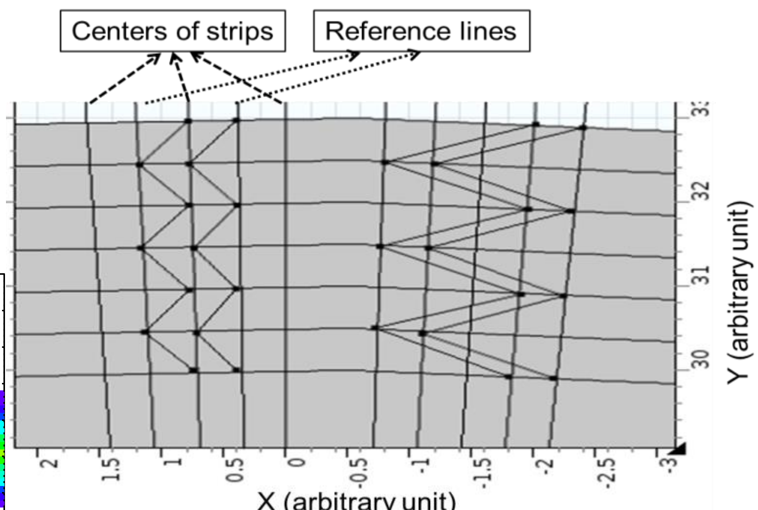
Zig-zag structure previously used





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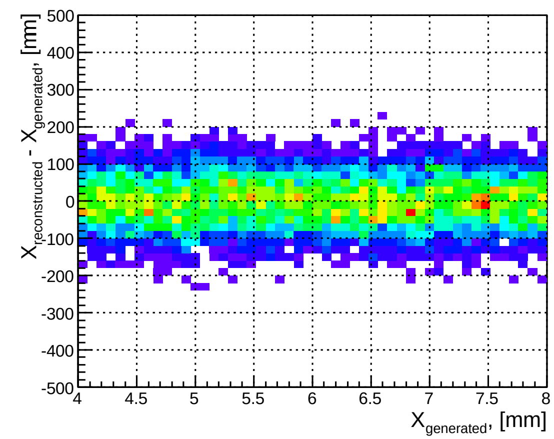
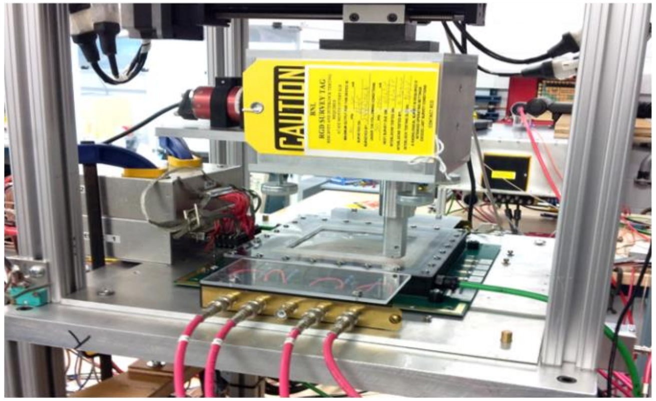


Progress @ Florida Tech

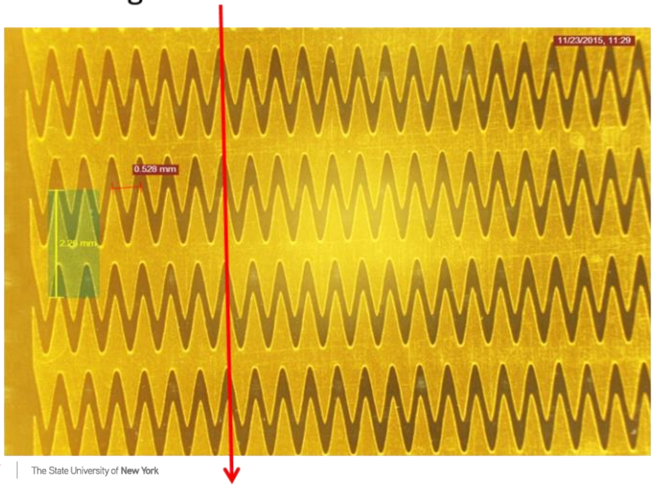
Experimental measurements of the non-linear responses.



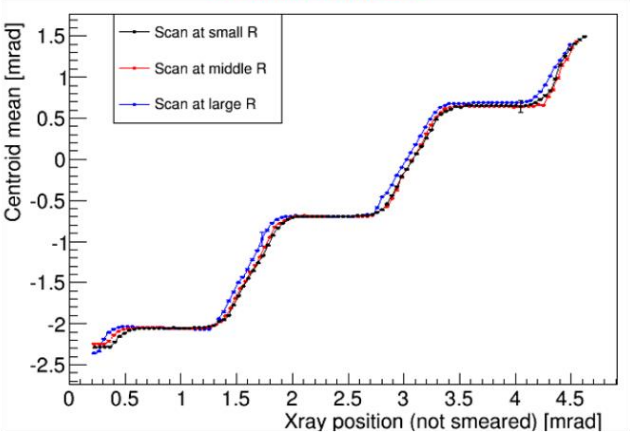
2D motor and collimated X ray gun setup at BNL. Used to precisely scan a 10 x 10 cm^2 GEM detector.

Scanned zig-zag boards in Nov. 2015; readout FADCs instead of APV25: no saturation issue! Data to be analyzed.

Scan along at three different R.

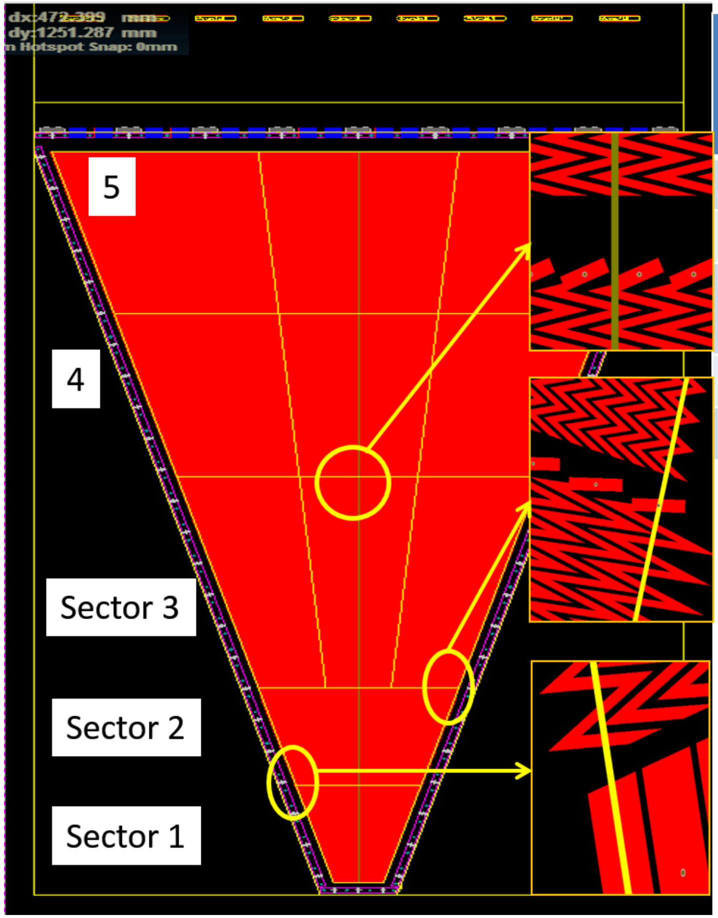


First scans (in July 2015) with APV25 chips → saturation issue



Progress @ Florida Tech

Design of the new zig-zag board for reading out the EIC common GEM prototype



Sec. No.	Strip type	No. of strips	Angle pitch (mrad)	Length of sector (cm)
1	straight	128	4.14	12
2	zig-zag	128	4.14	12
3	zig-zag	384 (=128*3)	1.37	22
4	zig-zag	384	1.37	22
5	zig-zag	384	1.37	22

- Plan to produce r/o on foil material (<200 μm thickness) → total detector material is reduced
- Divide the r/o area into 5 sectors, use straight strips in innermost sector
- Total **number of channels is 1152** (=128*9)
- 9 APV hybrids will be needed to read out full detector
- Based on a 2-layer design, routing of strips to connectors for APVs is complete, Gerber files have been produced, ready to be sent out to companies for quotes

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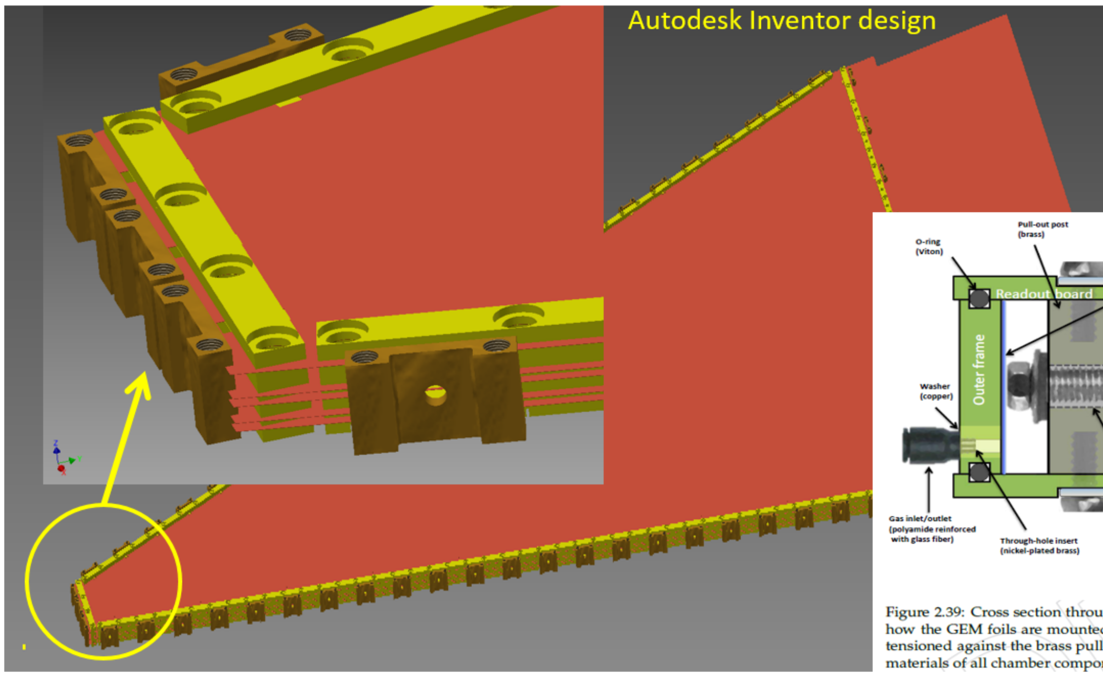
Progress @ Florida Tech

The **modified mechanical stretching method** for the GEM prototype assembly



Mechanical stretching for CMS GEM GE1/1

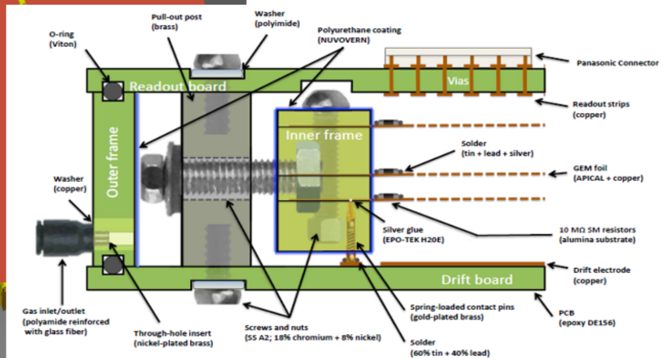
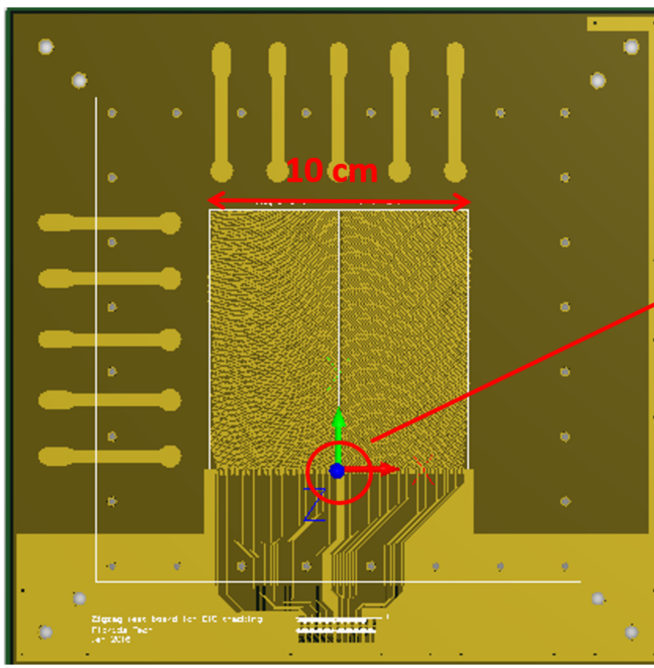


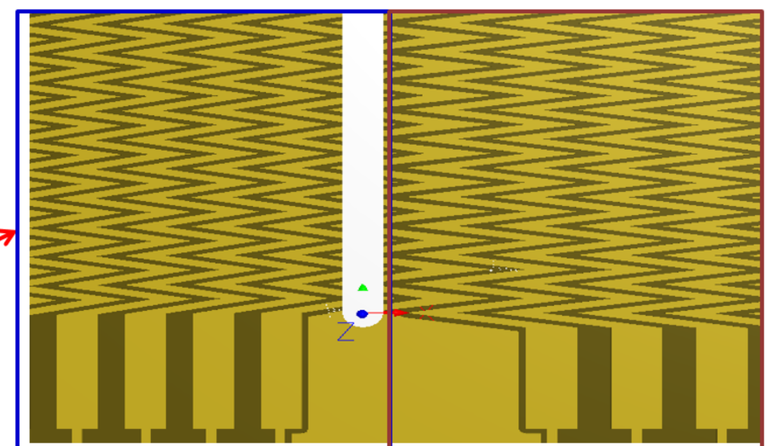
Figure 2.39: Cross section through inner and outer chamber frames and GEM foils that shows how the GEM foils are mounted within the GE1/1 chamber so that they can be mechanically tensioned against the brass pull-out posts without deforming the drift or readout boards. The materials of all chamber components are specified.

- CMS mechanical stretching method puts drift and readout on solid PCBs; GEM stack contains 3 GEM foils
- **Modified method makes stack of 5 foils (3 GEM foils, 1 drift foil and 1 r/o foil). Supporting structures are frames with windows (thin foil, e.g. aluminized mylar, can be used to seal gas) → that radiation length in active area will be minimized**
- Investigating new materials with higher strength for supporting frames such as carbon fiber frames

Progress @ Florida Tech

Test board (for 10 x 10 cm^2 GEM) **with new zig-zag structures** has been designed, production at PCB factory, soon to be tested!





Left: zig-zag strips (56 strips, 4.14 mrad angle pitch) have exactly same parameter as strips in the sector 2 in new 1 m zig-zag design.

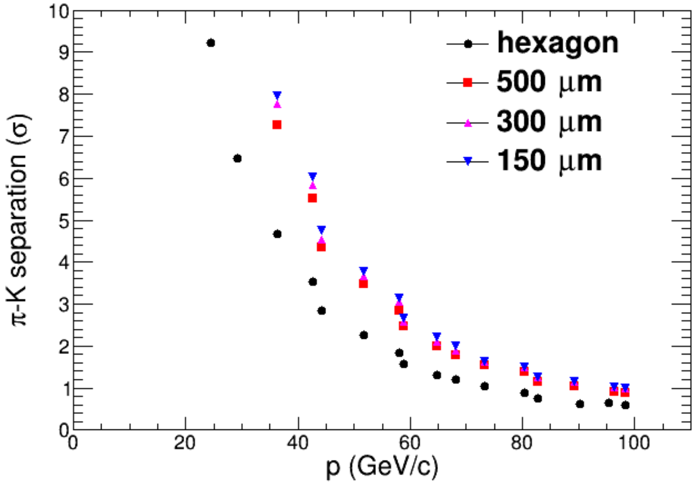
Right: 45 strips (1.37 mrad angle pitch) from sector 5 in new 1 m zig-zag design.

Progress @ Stony Brook

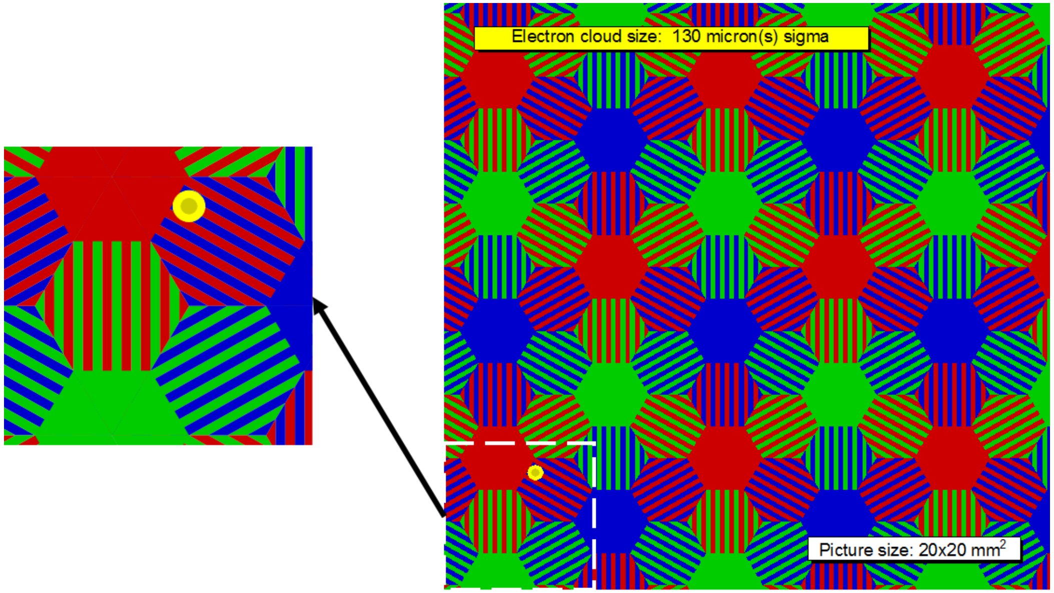
- Improvement of position resolution by means of charge dispersion not feasible
- The RICH detector is an anomalous case of position resolution:
  - Improved position resolution will improve device performance only when it is the limiting factor: σ=500 μm is the "cross-over"
- Catch 22:
  - For 2mm pads, resistive charge division is way better than $\sigma = \frac{2\,mm}{\sqrt{12}} = 580\mu m$
  - For larger sized pads, resistive charge division helps little
  - Trackers would benefit from resistive charge division (e.g. hybrid gain stage)
  - The RICH would not benefit since 2 mm pixels are already near the diffusion limit
- To continue with a tracking-driven interest we would:
  - Optimize charge dispersion calculations
  - Apply resistive layer on simple pad plane
  - Verify performance with x-ray gun

Progress @ Stony Brook

- New approach to improve position resolution based on Alexander Kiselev's studies



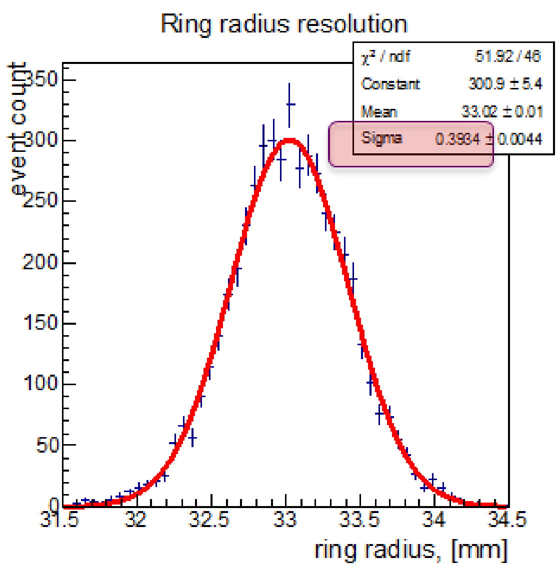
Separation power for various readout point resolutions.



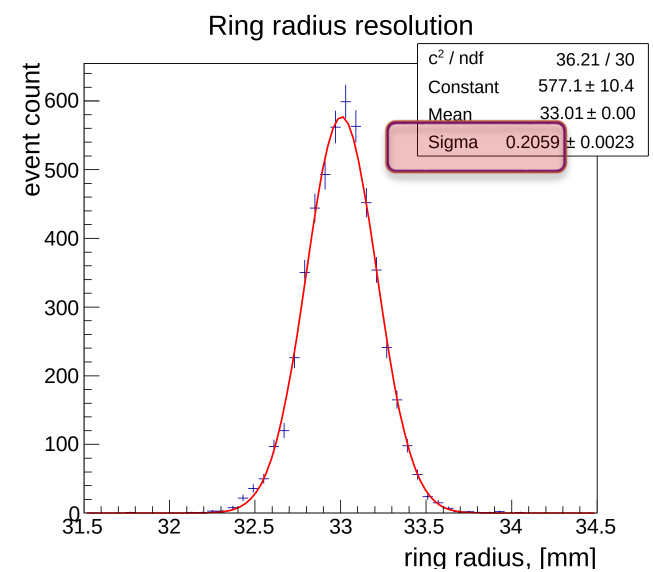
Interleaving pattern for hexagonal readout pad

Progress @ Stony Brook

- New approach to improve position resolution based on Alexander Kiselev's studies



Simulated parameters with input from measurements at test-beam campaigns



Ring radius resolution for an interleaved pad structure

- Factor *2* improvement in ring radius resolution

Progress @ Stony Brook

- Refurbishment of evaporator "Big Mac" for large mirror coating started

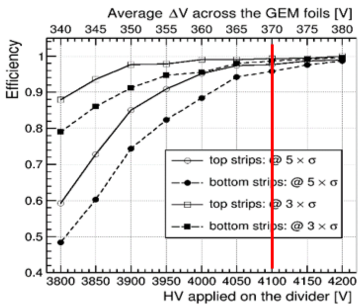
Large size evaporator "Big Mac" at SBU

Progress @ University of Virginia

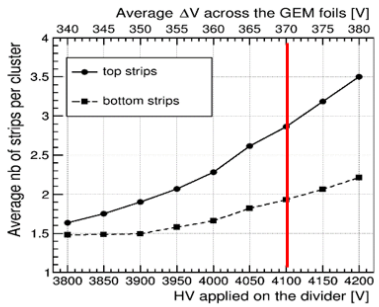
Past GEM R&D activities @ UVa: EIC-FT-GEM Prototype I

- Trapezoid shape **1-m long** triple-GEM (3-2-2-2): widths at the inner radius and outer radius equal **to 23 cm and 44 cm** respectively.
- Readout board: flexible 2D U-V strip readouts (COMPASS style) with a **pitch of 550 µm,** top layer (**140 µm, wide U-strips**) run parallel to one radial side of the detector and bottom layer (**490 µm, V-strips**) run parallel to the other side.

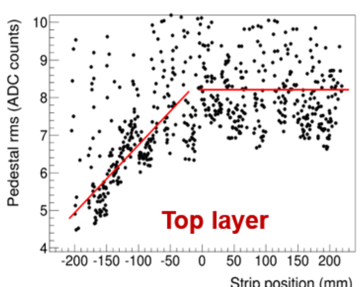
Efficiency vs. HV

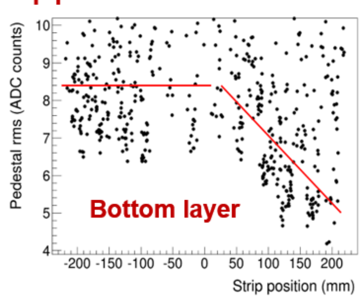


Cluster size vs. HV

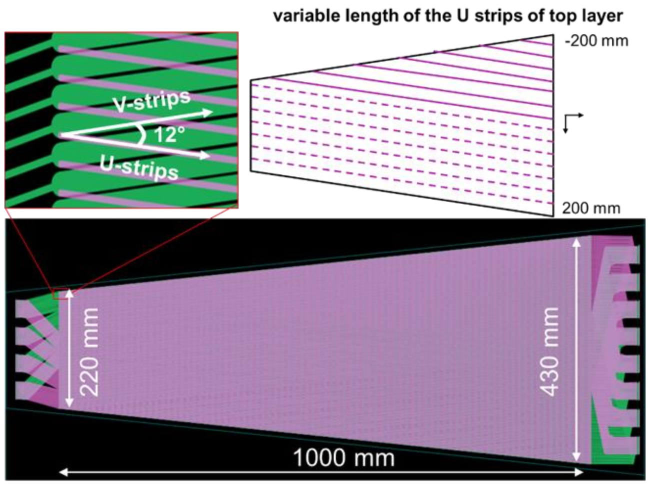


Distribution of the strip pedestal noise

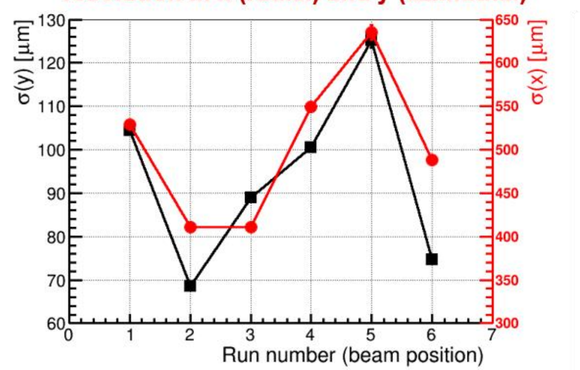




U-V strip Readout of EIC-SoLID GEM Proto I



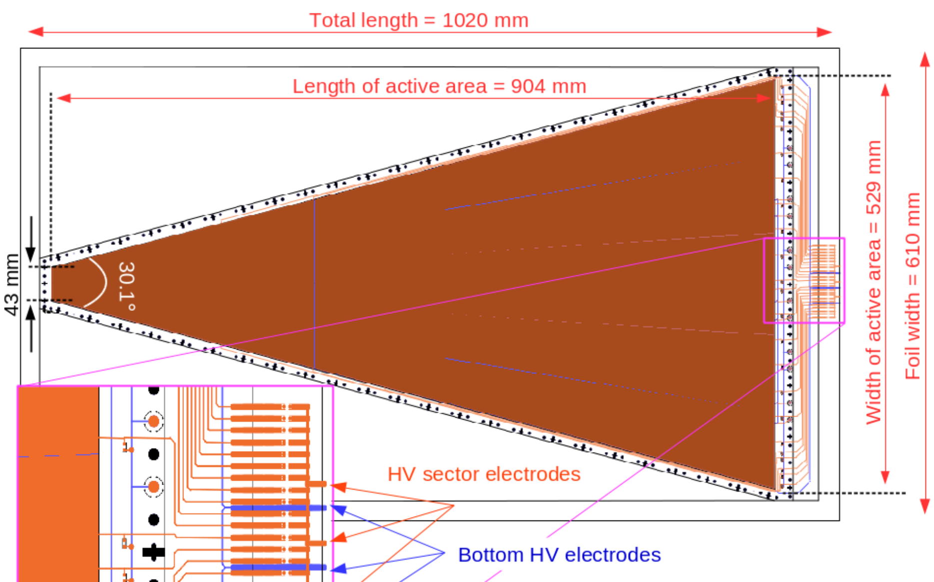
resolution in x (radial) and y (azimuthal)



Progress @ University of Virginia

Future GEM R&D activities @ UVa: EIC-FT-GEM Prototype II

Common GEM foil for EIC-FT-GEM proto II
(design by A. Zhang @ Florida Tech)



- UVa, FIT, TU groups share a common GEM foil design
- HV distribution to the HV sectors is specific to each group

Common GEM foil for EIC Forward Tracker R&D:

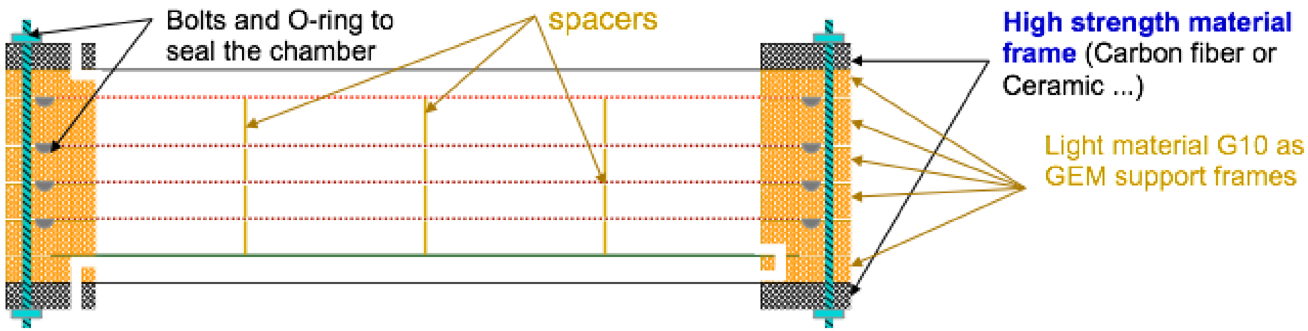
- ✓ Common GEM foil design developed by three groups at UVa, Florida Tech (**M. Hohlmann**), and Temple University (**B. Surrow**).
- ✓ Active area: trapezoid foil with a length of **903.57 mm,** width at both ends equal to **43 mm and 529 mm,** opening angle **30.1º.**
- ✓ Opening angle of the trapezoid is **30.1 deg**., allows some overlap when making a disk from 12 detectors.
- ✓ All HV sectors connections and gas flow structure are made on the large radius end.

Future GEM R&D activities @ UVa: EIC-FT-GEM Prototype II

New assembly method:

- ✓ Ongoing work on the design of proto II of Forward Tracker Detector R&D of EIC
- ✓ Similar assembly technique for the pRad GEM chambers @ JLab
- ✓ Foils are glued to frames but frames **not glued together** but sealed with O-rings and bolts could be re-opened.
- ✓ Honeycomb support are removed for a low mass detector.

Novel assembly method for light weight GEM for EIC/SoLID



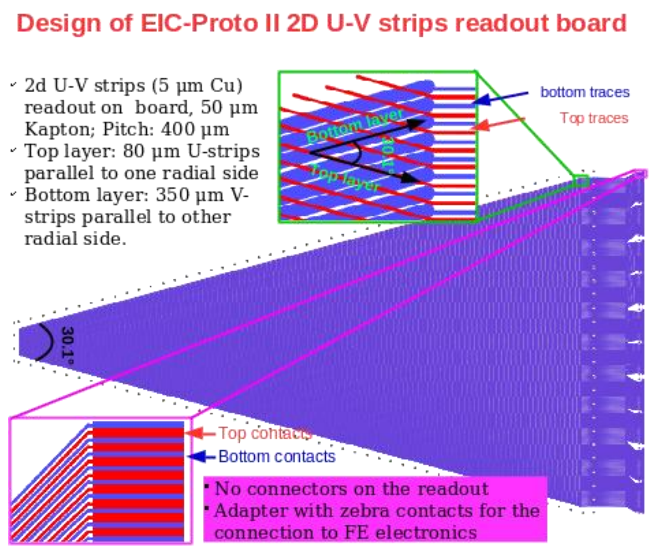
Future GEM R&D activities @ UVa: EIC-FT-GEM Prototype II

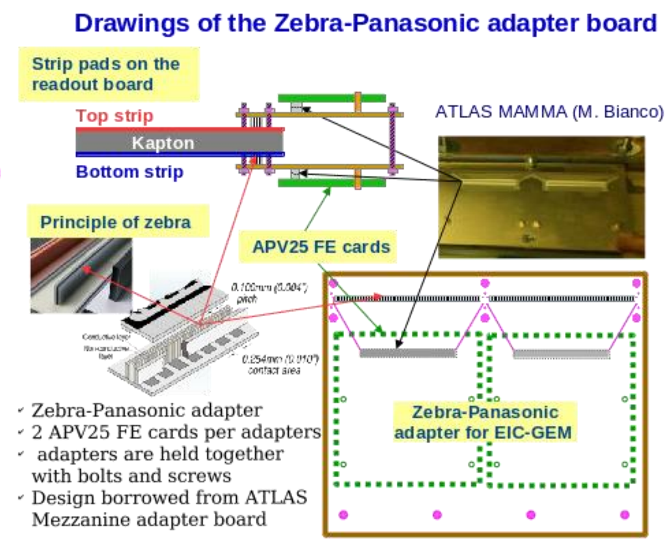
Upgrade of the U-V strip 2D readout board

- ✓ The readout strip pitch is equal to **400 µm** to improve spatial resolution, reduce pedestal noise and strip occupancy
- ✓ Larger U-V strip stereo-angle of **30.1º** provide significant improvement of the spatial resolution in the radial direction
- ✓ Electrical contacts between the strips and the FE electronics done with **zebra connectors** on the outer radius side of the detector.
- ✓ **no mounted connectors and metallized holes (vias)** on the readout board ⇨Lower production cost and risks

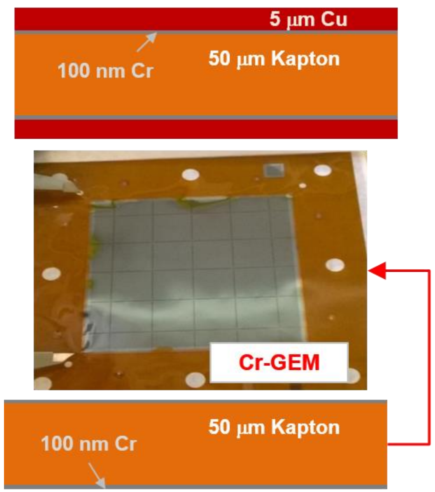
Zebra-Panasonic adapter board

- ✓ Needed to read out the chamber with he existing APV25-SRS Front End Cards, design almost ongoing
- ✓ In the final version, for EIC GEM trackers, the zebra strips will be directly on the FE cards





Low-Mass GEM R&D: Chromium GEM foil (Cr-GEM)



Triple-GEM with standard GEM foil

	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	5	8.96	14.3	1	0.0350	0.0045
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	5	8.96	14.3	0.8	0.1678	0.0215
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5	8.96	14.3	0.2	0.0070	0.0009
Copper-350	1	5	8.96	14.3	0.75	0.0262	0.0034
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.471	0.090

Triple-GEM with Cr-GEM foil

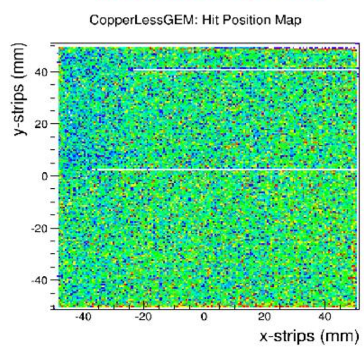
	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0	8.96	14.3	0.2	0.0000	0.0000
Copper-350	1	0	8.96	14.3	0.75	0.0000	0.0000
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	0.235	0.060

About 50% reduction in the amount of material in a EIC-FT-GEM with Cr-GEM

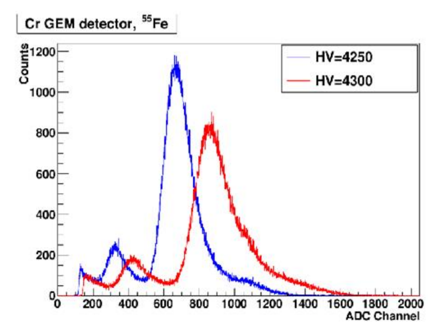
Cr-GEM foil:

- ✓ Copper (Cu) clad raw material comes with 100 nm Chromium (Cr) layer between Cu and Kapton, 5µm Cu layers removed, leave only 100 nm residual Cr layers as electrodes, **Cr-GEM foils provided CERN PCB workshop**
- ✓ Using Cr-GEM foil lead to almost 50% reduction of the material of an EIC light weight **triple-GEM detector**: this is because the material in a lightweight triple-GEM is dominated by the GEM foils & readout board

Response uniformity



ADC Spectrum with Fe55

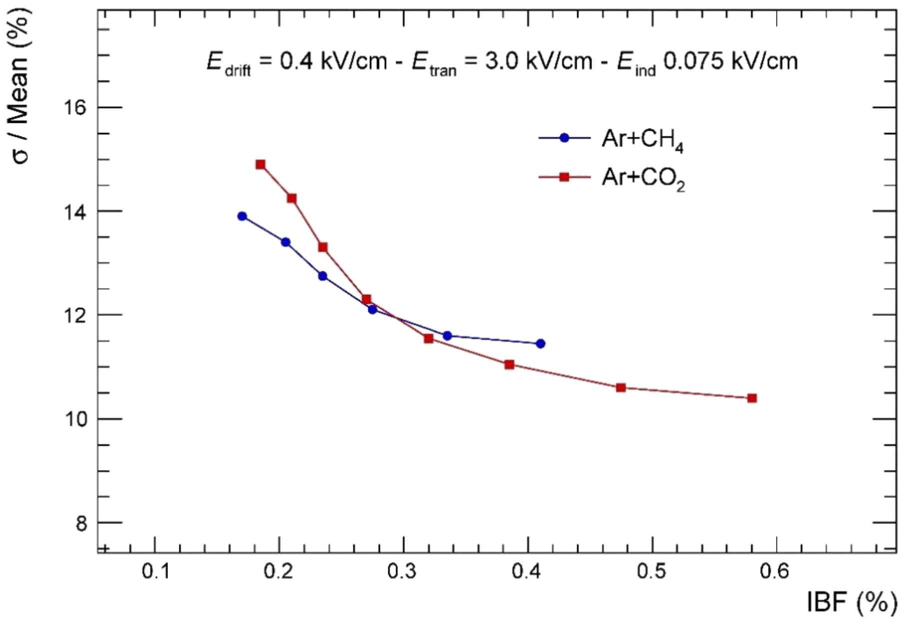


Stony Brook University | The State University of New York

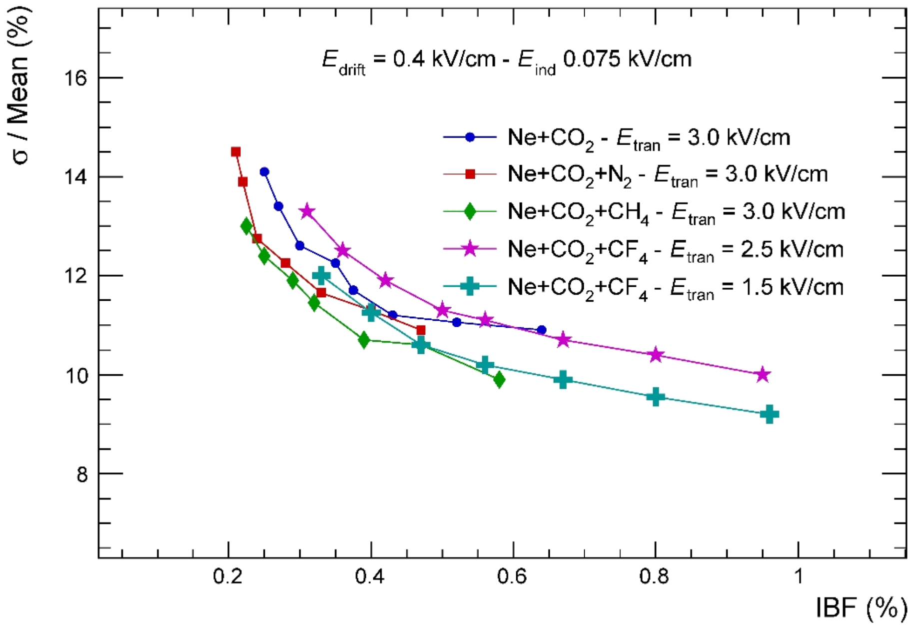
Progress @ Yale University

- Analysis of 3-D coordinate GEM near completion
- Hybrid gain structure for TPC readout
  - Two GEMs + MicroMegas → possible minimization of Ion Backflow IBF
  - Measurements with different readout plane geometries and different gas mixtures performed

Progress @ Yale University



*Energy resolution (σ of ^{55}Fe peak) vs Ion Back Flow (IBF) for **Argon** gas mixes.*

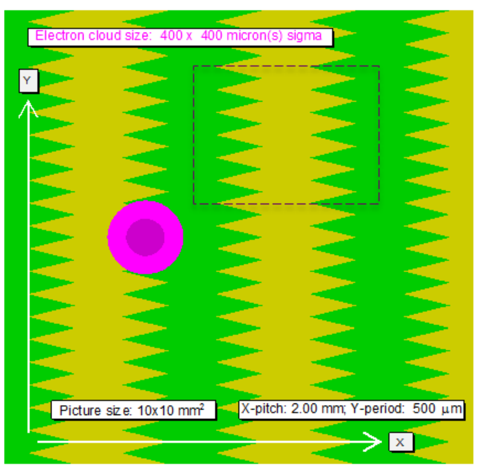


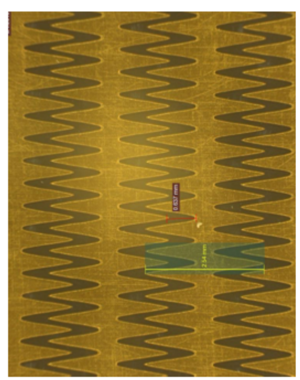
*Energy resolution (σ of ^{55}Fe peak) vs Ion Back Flow (IBF) for **Neon** gas mixes.*

Zig-Zag Strip Studies

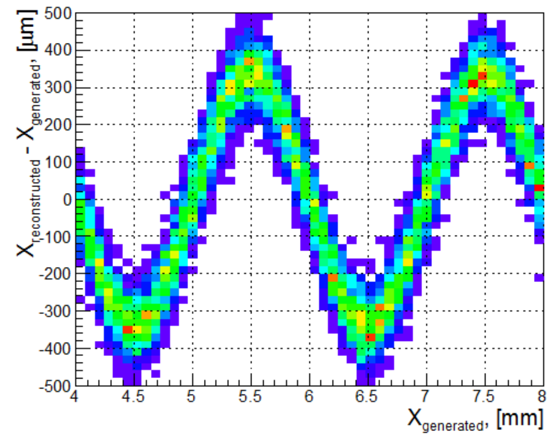
- **Problems with existing FIT & BNL designs:**
  - Strongly non-linear behavior of residuals after weighted mean centroid calculation
  - Correction depends on the electron cloud size
  - Wide regions around strip centers are insensitive to track location (charge collected by single strip)

- FIT design: model
- The real PCB

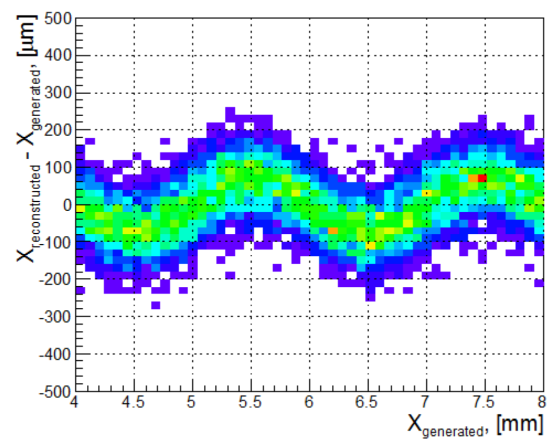




Example: residuals across 2 strips



200 µm e⁻ cloud width



600 µm e⁻ cloud width

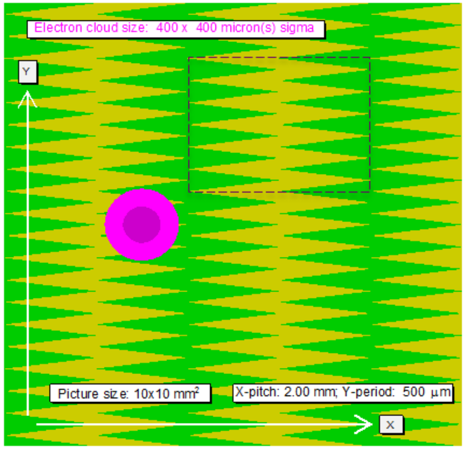
Zig-Zag Strip Studies

An idealized simulation environment was developed in ROOT in order to optimize the zig-zag strip layout

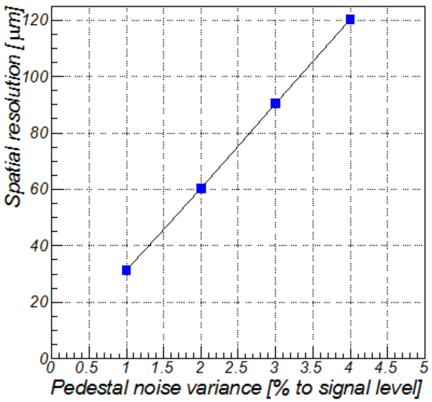
It was demonstrated in particular, that "linear response" geometry should not suffer from non-linearity problems

-> a complete simulation with electric field distortions and electron drift through GEM stack is in progress

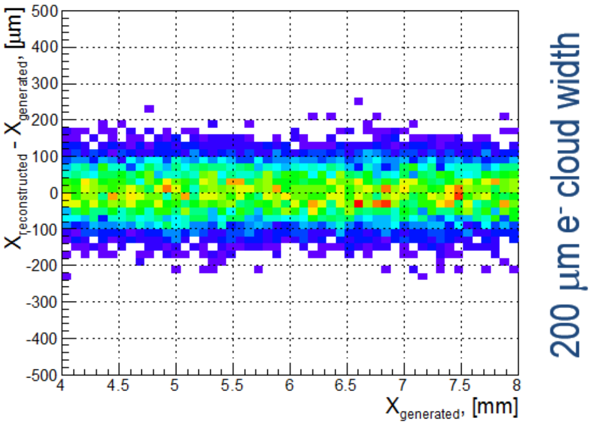
- "Linear response" model

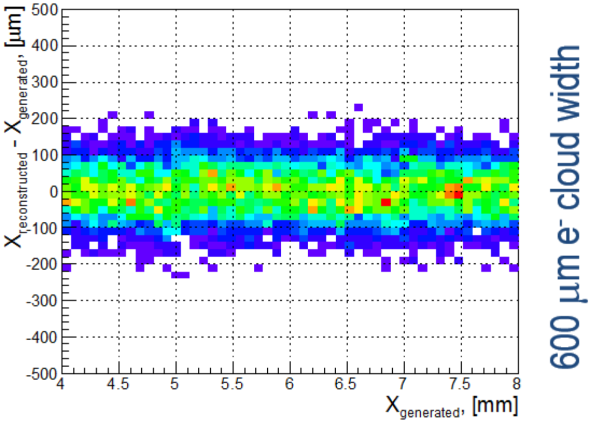


- Spatial resolution as a function of pedestal noise



Example: residuals across 2 strips

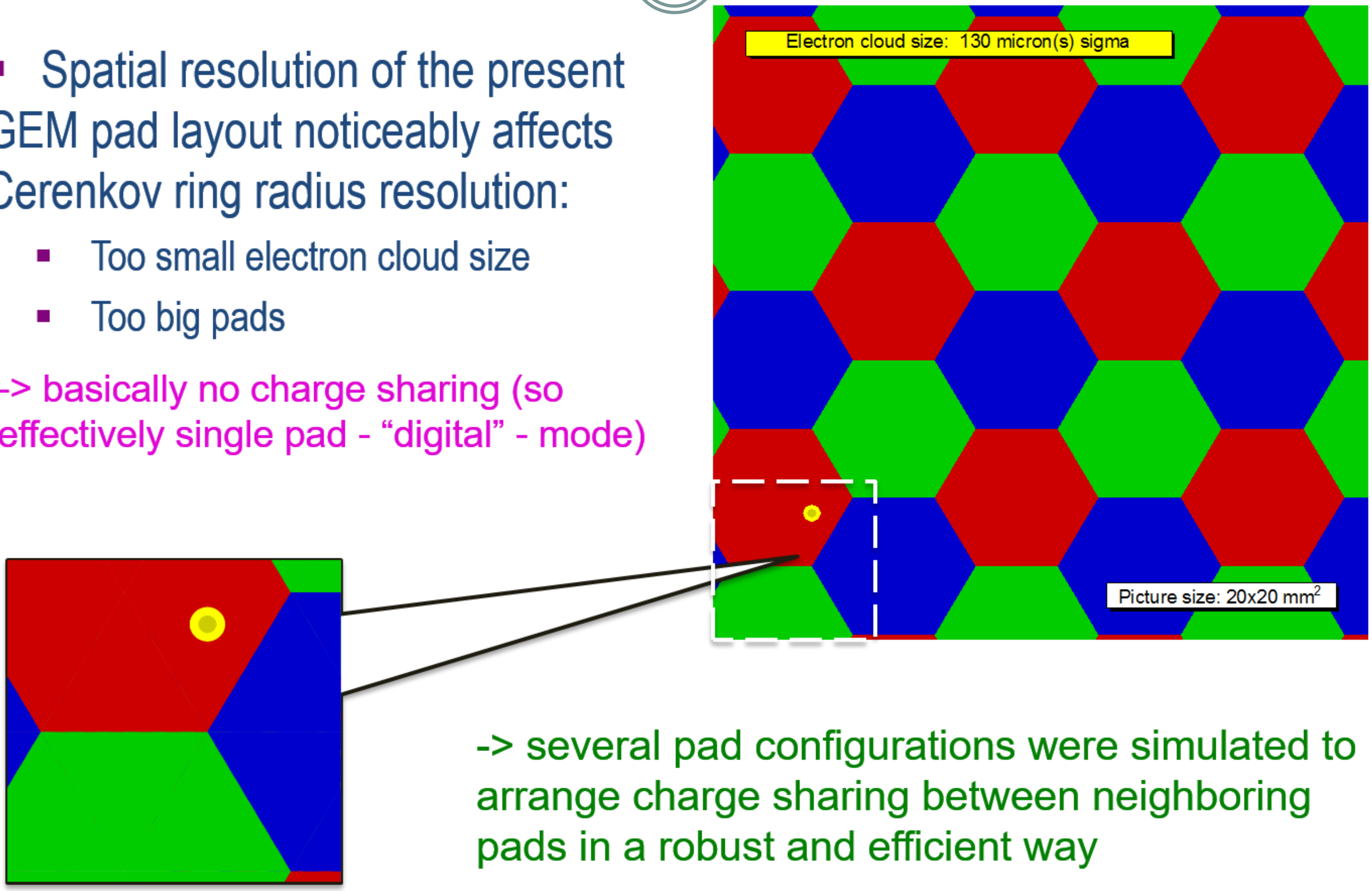




Strip-Pad Studies

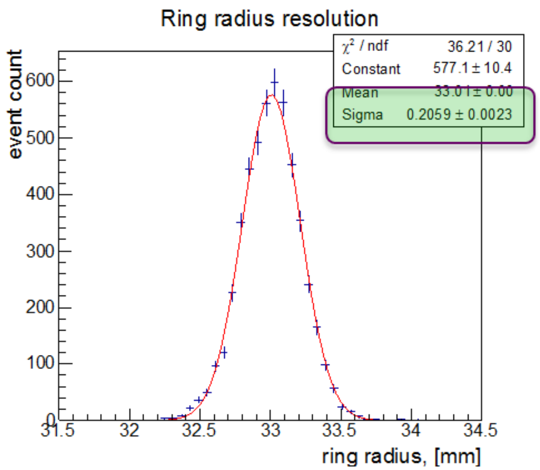
- Spatial resolution of the present GEM pad layout noticeably affects Cerenkov ring radius resolution:
  - Too small electron cloud size
  - Too big pads

-> basically no charge sharing (so effectively single pad - “digital” - mode)

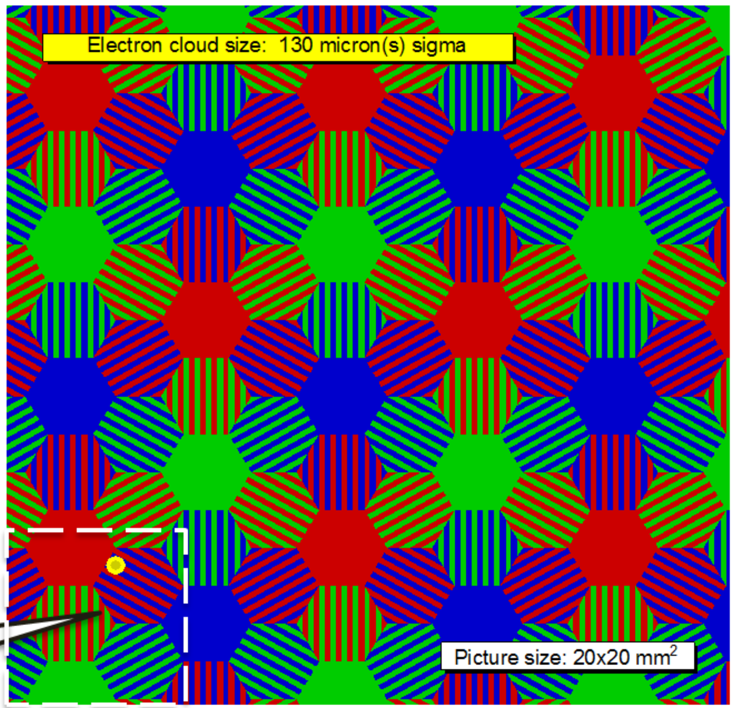


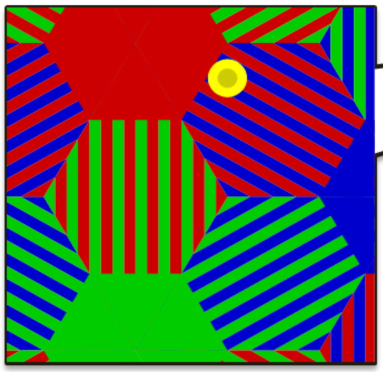
-> several pad configurations were simulated to arrange charge sharing between neighboring pads in a robust and efficient way

Strip-Pad Studies



-> simulation shows ~200 μm ring radius resolution compared to ~400 μm in the present configuration





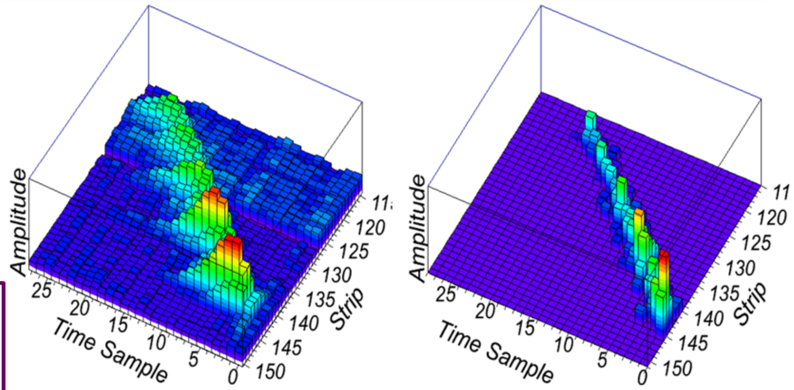
- A "snowflake" configuration with a ~50:50 charge sharing in "zebra" overlap regions seems to be the best candidate
- Photon impact area is effectively restricted by a hexagon with a factor of 2 smaller size (thus expect x2 gain in resolution)

Mini-drift GEM pulse shape unfolding

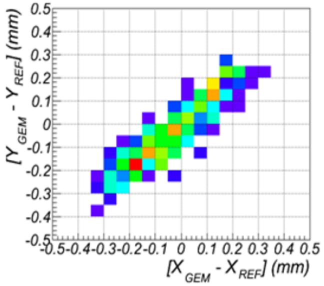
- The problem: long APV25 shaping time smears original signals over several time slices and strongly affects weighted mean centroid calculation

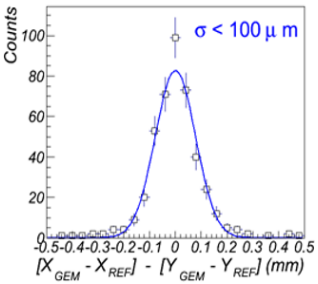
One can try to unfold original energy deposits for each strip and each time slice using known APV25 response to a δ-function-like signal

Detector in the "diamond" orientation to the beam



- Raw signal
- Same signal after unfolding





COMPASS-style readout: 2D XY-residual correlation after unfolding

-> if in addition to unfolding one eliminates SRS trigger jitter in the data (which indeed cancels out in XY-residual difference distribution) spatial resolutions of better than 100 μm can be attained even at very large track angles

Summary

- Progress at all fronts in eRD6 project
- Money well invested -> all efforts published
- Experience gained in test-beam campaigns consistently implemented into further development
- Improving detector performance
- Introducing procedures to improve detector handling
- Excellent collaboration between hardware development and simulation
- New ideas coming up
- Post-doc at Florida Tech crucial for further success in eRD6

Outlook

- New ideas will be translated into new projects
  - New zig-zag strip boards developed
  - New ***snowflake*** pad pattern developed
  - New pattern for TPC readout pads
- New ideas to be tested in further test-beam campaigns

FYI – FY17

- Anticipate the following funding request for the next round of EIC R&D funding in FY17

Brookhaven National Lab:
1. Support for beam test - **$15k**
2. Travel - **$3k**
3. Expendable materials and supplies - **$12k**
4. Design and materials for new chevron readout patterns - **$10k**
5. Parts and materials for investigation of GEM/Micromegas operation - **$10k**
6. New optics for VUV spectrometer - **$10k**

Total without overhead - $60k
Total with overhead - $90k

Florida Tech:
1. Salary for Aiwu (fully loaded) - **$95k**
2. Construction of next EIC FT prototype - **$14k**
3. Travel - **$7k**
4. Support for beam test - **$7k**

Total fully loaded - $123k

Stony Brook University:
1. Design and fabrication of snowflake readout patterns - **$12k**
2. Expendable materials and supplies - **$5k**
3. Support for beam test - **$10k**
4. Travel - **$5k**

Total without overhead - $32k
Total with overhead - $50k

University of Virginia:
1. Materials and Production of (U-V strips) readout board including the Zebra-Panasonic adapter boards - **$10k**
2. Design and materials and production of GEM support frames - **$4k**
3. Expendable materials and supplies - **$4k**
4. Travel - **$3k**
5. Support for beam test - **$10k**

Total without overhead - $31k
Total with overhead - $49k